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Risk analysis for RoPax vessels: A case of study for the Strait of Gibraltar

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ABSTRACT

The Strait of Gibraltar (SOG) is one of the principal navigation areas in the world. The maritime traffic registered in the area is approximately 110,000 ship movements per year, where thirty-three per cent of total traffic involves roll on/roll off passenger (RoPax) ships which run scheduled voyages between ports in the area. There are presently many accidents involving this type of ship being reported. Although these incidents have serious consequences, both based on a financial scale and regarding human safety, there is no formal maritime risk analysis study for this area carried out to date. The aim of this paper is to present the results of a risk analysis for RoPax ships operating in the SOG, based on accidents statistics covering the period 2000–2011. The work has been performed using the two first steps of the IMO Formal Safety Assessment methodology: Hazard Identification and Risk analysis. To identify the hazards and their associated scenarios and quantify, their frequencies and consequences, the Historical Accident Data Analysis and Expert Judgement techniques were used. A risk matrix has been drawn up to calculate the risk indices of the identified hazards. A comparative study of the accident frequencies obtained from similar previous studies is also presented in the paper. A high-level model risk for collisions was established through the elaboration and quantification of an Event Tree, calculating the individual and social risks. The conclusions of this study could serve as recommendations to be used in a subsequent decision making process.

1. Introduction

Ships designed to carry passengers and roll on/roll off cargo (RoPax ships) are among functional types of ships. The flexibility, ability to integrate with other transport systems and operating speed, has become extremely popular in many routes. However, as past accident statistics demonstrate, there are numerous examples of accidents involving RoPax ships. Consequences of these accidents include large numbers of lost lives, serious damage to the environment and economic costs. The capsize of the *Herald of Free Enterprise* in 1987, the fire of onboard the *Scandinavian Star* in 1990 and the sinking of the *Estonia* in 1994, are notable cases of well-known and investigated maritime casualties. Unfortunately, major maritime disasters involving RoPax ships still occurring in the last decade, as the sinking of the ferry *Al Salam Boccaccio 98* in February 2006, and more recently the sinking of *Sewol* in April 2014.

Studies relating to shipping risk assessment have received growing interest in the last years. Risk assessment has been very helpful for the review and development of new rules and regulations in order to reduce accidents and improve maritime safety. Many methods and applications for maritime transportation risk analysis have been presented in the literature. Goerlandt and Montewka (2015) present a complete review of scientific approaches to risk analysis focusing on applications addressing accidental risk of shipping in a sea area. The review covers the period from 1970 to 2014, up to a total of 58 applications.

A number of risk assessments studies applied to RoPax ships can be found in the literature. Det Norske Veritas (DNV, 1996) carried out a study on RoPax ships sailing in the North West of Europe; focusing on the investigation of operational dangers and causes of such vessels and quantify, when possible, their frequency and consequences through the creation of a risk model based on Event Trees (ET). Van Dorp et al. (2001) and Merrick et al. (2003) carried out both risk assessments on ferries at specific geographical areas, Washington state and San Francisco Bay, respectively. Otto et al. (2002) submitted a risk analysis for these ships to study the damages produced from collision and grounding. At the same time, the International Maritime Organization (IMO) adopted in 2002, the Formal Safety Assessment (IMO, 2002); a structured and systematic methodology, aimed to increase maritime safety based on risk analysis. Accordingly, we can find studies as the hazard identification related to casualties of RoPax vessels (Antao and Soares, 2006) which used the FSA methodology. Another risk analysis study for the

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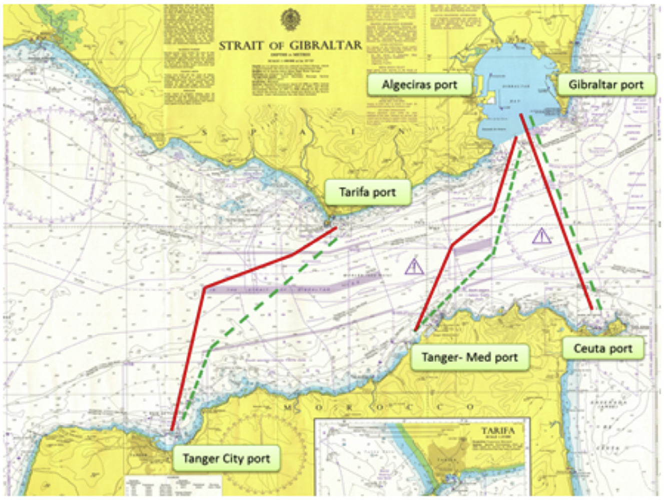

Fig. 1. Nautical chart of the Strait of Gibraltar with the ports located in the area. The continuous lines represent the southbound routes and the discontinue lines are the northbound routes performed by the RoPax ships.

world-wide RoPax fleet (Konovessis and Vassalos, 2007; Konovessis et al., 2008; Guarin et al., 2009) was carried out as part of the activities of the SAFEDOR Integrated Project (SAFEDOR, 2005–2009) and submitted to IMO (IMO, 2008a). In addition, Gemelos and Ventikos (2008) present a risk assessment on Greek passenger ships in order to estimate the safety level of Greek coastal shipping. More recently, other studies (Montewka et al., 2014; Goerland et al., 2014) are focusing in the development of a novel framework for estimating the risk and consequences resulting of open sea collisions involving a RoPax, using tools such as Bayesian Belief Networks (BBN) to calculate the fatalities risk.

On this background, in this paper we present results of a risk analysis study for RoPax ships in a specific area, the Strait of Gibraltar (SOG). There is no earlier study available in the literature to the maritime risk analysis in this specific area, with exception of (Piniella and Walliser, 2013) which, however, focused in drawing the taxonomy and distribution of maritime emergencies in the area.

The Strait of Gibraltar is one of the main shipping areas in the world. It is well-known for its high volume of maritime traffic, which is dependent on a Maritime Organization System, mainly controlled by a Traffic Separation Scheme (TSS). The aim of this TSS is to organize traffic and to avoid the occurrence of maritime accidents. However, this area is prone to problematic conditions which lead to the SOG being a hazardous area for safe maritime navigation. The weather is one such troublesome element due to the continuous winds from either the east or west; there is also frequent fog in the area. In addition, there is a limited geographical area intended for navigation, aggravated by frequent geopolitical disputes between the different states who lay claim to the waters and disagree over who has control.

Of the total traffic registered in the area (approximately 110,000 vessel movements per year), 33% involves RoPax ships, which run regular voyages between the ports in the area. In 2012, 35,925 movements of RoPax were recorded, representing an average of 98 daily movements.[1] And although these ships are extremely common in this area, they are involved in a high number of accidents as a consequence of the hazards associated to this type of transport and the area in which they sail.

RoPax ships sail in the area according to three route types connecting the following ports:

Type: Ropax	
Flag: Morocco	
Built year 1996	
IMO Nº: 9112777	
Gross Tonnage: 14,221	
Deadweight: 4,030 t	
Length: 136.4 m	
Beam: 24.6 m	
Passengers: 698	
Cargo units: 60 units or 360 cars	

Fig. 2. Example of Ropax ships and its main particulars.
Source of the picture: http://www.marinetraffic.com

a) Route between Algeciras port and Ceuta port
b) Route between Algeciras port and Tanger Mediterraneo port
c) Route between Tarifa port and Tanger City port

Fig. 1 shows the ports located in the area as well as the RoPax ship routes. It is noticed that these routes cross the TTS located in the area, which means the RoPax ships are constantly cut crossing the main SOG maritime traffic, increasing the risk of collision. In addition, the modification of the TTS in 2007, on the occasion of the opening of the service Tanger Mediterraneo port in 2009, has contributed on an increase of cross points of conflict in the area, particularly in the Eastern part.

RoPax fleet compromises of ferries and High Speed Craft (HSC) above 1000 GT. During the period covered by the present study there were, on average, 16 RoPax ships covering these services. One example of a common RoPax ship in the area can be seen in Fig. 2.

The aim of this study is to carry out a risk analysis for RoPax ships navigating in the SOG based on accidents statistics collected for the period 2000–2011. The work has been performed in accordance with the IMO FSA guidelines. The first objective consists of identifying the hazards and their associated scenarios and quantifying, to the extent possible, their frequencies and consequences. In order to do this, the Historical Accident Data Analysis and Expert Judgement techniques were used. A risk matrix has been drawn up which is supported by the opinion of experts in order to calculate the rates and levels of risk. Also, a high-level model risk for collisions will be established through the elaboration and quantification of an ET. It is used to determinate the safety level of RoPax calculating the individual and social risks. A study of the accident frequencies obtained from similar previous studies has also been carried out. Finally, the conclusions of this study could serve as recommendations for a subsequent decision making process.

2. Methodology

2.1. Approach adopted

The FSA, adopted by the International Maritime Organization (IMO) in 2002, is a structured and systematic methodology, aimed at enhancing maritime safety. This includes the protection of life, health, property, and the marine environment, by using risk analysis and cost benefit assessment. The last update of the FSA guidelines was in 2012 (IMO, 2012).

FSA consists of five steps as follow:

1. Identification of hazards
2. Risk analysis
3. Risk control options
4. Cost benefit assessment, and
5. Recommendations for decision-making

This paper is focused in the step1: hazard identification and step 2: risk analysis.

[1] Traffic data have been provided by Spanish Maritime Safety Agency http://www.salvamentomaritimo.es/.

2.2. Hazard identification

The aim of this step is to identify a list of hazards and their associated scenarios prioritized by risk levels. To determine these hazards standardized techniques are used. These hazard identification tools give answers to questions such as “What can go wrong?” and “why?”

The guidelines for carrying out an FSA (IMO, 2012) recommend using a combination of creative and analytical techniques for developing the hazard identification (HAZID). The creative element aims to ensure the process uses foresight, rather than just being limited to those hazards that have materialized in the past. On the other hand, the analytical element guarantees that experience is used for full advantage by using the information available. This study has been carried out using *Historical Accident Data Analysis* and *Expert Judgement* techniques. It follows that the former one is analytical and makes use of the information available on accidents that have happened in the past, while the latter one is creative and assures that this research will not be limited to only those hazards which have triggered accidents.

2.2.1. Historical accident data analysis

Historical analysis has been carried out using the IHS Fairplay Sea-Web® database (earlier known as Lloyds Register Fairplay) from 2000 to 2011. The information registered in this database has been supported by the official reports of the accidents, which were produced by the different government organizations.

2.2.2. Expert judgment methodology

Expert Judgement involves using the information and data given by qualified individuals in order to solve problems or make decisions in a range of areas (Skjong and Wentworth, 2001; Meyer and Booker, 1991). An expert is defined as a person with experience in the area of study, whose expertise is recognised by their peers in this field. In this way, expert judgement generates opinions based on the individual training and experience of those who participate. The experts give information, evidence, opinions, and assessment of the subject. In our study, the opinions of the experts have been extracted using the Delphi method.

A Delphi study involves choosing a group of experts who are asked their opinion about a particular matter. This information is then gathered together so that subsequent questionnaires can be designed with the aim of finally reaching a consensus. All the time, the complete autonomy of the participants is respected (Astigarra, 2003). It could be considered as a feedback process, where a unique consensus is reached through the completion of diverse questionnaires. One of the advantages of this method is that it does not require experts to come together in group sessions. In this manner, any view expressed will not be conditioned upon personal conflicts, pressures from within the group, the appearance of a leader, and so forth.

Thus, the process was divided into three stages: choosing the experts, elicitation and aggregation, phases respectively. The elicitation phase refers to the process of suggesting opinions or expert judgements through special means. This is usually supplied through interviews and/or questionnaires. The aggregation phase is the converging of the different expert opinions proposed in the study (Meyer and Booker, 1991).

Stage 1: Choosing the experts

The first step was to choose the experts who would take part in the study. In this case, the number of participants was 15, where the experts were: 7 captains and 5 officers with experience in maritime traffic of the area, 2 members of the Maritime Pilot's Association of the Bay of Algeciras and 1 Flag State surveyor.

Stage 2: Elicitation

Once the participants were chosen, the process for obtaining the information was outlined. The process used was the Delphi method, through the use of questionnaires. In order to draw up the questionnaires, earlier study carried out by Åland Sea FSA (Nyman et al., 2010) was used as a reference.

Based on the process outlined above, a first 'open-end' questionnaire was designed, with the objective of identifying a list of hazards and their associated scenarios, which could result in a risk for maritime traffic in the SOG. The experts had to define those initial events which, in their opinion, could lead to undesirable events which would have negative consequences for people, property and/or the environment.

As this study focuses on risks during navigation, all hazards associated with the loading and unloading of people and vehicles, port manoeuvres, and mooring were excluded from the study.

Stage 3: Aggregation

With the results from the first questionnaire, a list was drawn up which included all the identified hazards. In total, there were 63 hazards related to maritime traffic. This list of hazards was re-introduced to the participants as a “closed-end” questionnaire, so that they could rank the hazards posing the greatest threat to RoPax ships. During this aggregation stage, the experts had to highlight the ten most significant hazards among the list of 63 hazards contained in the questionnaire.

2.2.3. Risk indices classification

The identified hazards have been classified according to their index of risk. The experts gave each hazard a rating depending on the frequency with which it occurs and the severity of the consequences. For this purpose, this study used the logarithmic frequency scale and logarithmic severity scale recommended by the IMO FSA guidelines (IMO, 2012) (See Tables 1 and 2). The combination of these scales result in a Risk Index, represented in the form a Risk Matrix.

2.3. Risk analysis

Risk analysis should lead to a thorough investigation of the causes and consequences of the associated scenarios to the major hazards identified in the HAZID. For that, probabilistic and deterministic techniques are used, which solve issues as: “how often?” and “what are the effects?”

Frequency is the number of occurrences of an undesirable event expressed as events per unit of time. In this paper, accident frequency was defined as the number of incidents divided by the number of ship years. Casualty statistics analysis has been carried out on the basis of historical data using the Sea-web database for the period 2000–2011. The fleet statistics for the same period was obtained by the Spanish Maritime Safety Agency.

Also, a high-level model risk for collisions in RoPax vessels under way at the SOG was established through the elaboration and quantification of an ET, as collisions are the most frequent accident involving RoPax ships

Table 1
Frequency index (IMO, 2012).

FI	Frequency	Definition	F(ship and year)
7	Frequent	Likely to occur once a month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during the ship's life	0.1
3	Remote	Likely to occur once per year in a fleet of 1000 ships, i.e. likely to occur in the total life of several similar ships	10^{-3}
1	Extremely remote	Likely to occur once in the lifetime (20 years) of a world fleet of 5000 ships.	10^{-5}

Table 2
Severity index (IMO, 2012).

SI	Severity	Effects on human safety	Effects on ship	S(fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe damage	1
4	Catastrophic	Multiple fatalities	Total loss	10

according to the accident statistics analysed for the SOG area.

ET is a standard technique recommended by the IMO FSA guidelines (IMO, 2012). The assignment of branch probabilities on the event tree was done on the basis of the accident statistics of the present study for the period 2000–2011, earlier research studies (DNV, 1996; IMO, 2008a,b; Konovessis et al., 2008) and expert judgment.

3. HAZID results

3.1. Historical accident analysis for RoPax vessels in the SOG

According to the Sea-web database, the accidents are classified according to six categories: sinking, fire or explosion, collision, contact, grounding, and damage caused to the hull or machinery.

Accidents involving RoPax ships during the period 2000 to 2011 in the SOG, include the following: 7 accidents caused by collision, 2 accidents caused by contact, 2 cases of damage to the hull or machinery and 1 accident involving fire or explosion. This total 12 incidents involving RoPax ships.

Given that the majority of the incidents come under the 'collision' category, this study will focus on identifying the hazards and causes associated with this type of accident.

With reference to Table 3, it is noted that the collision between *Al Mansour* and *Ciudad de Málaga* of 18/04/2007 ocurred in the port whilst *Al Mansour* was moored. Hence, in this respect, 6 out of the 7 collisions of Table 4 (86%) are collisions when the ship was under way and 1 collision (14%) when the ship was moored.

3.2. Analysis of the causes of collisions

In order to determine the causes of collisions which occurred in the SOG during the period from 2000 to 2011, it was necessary to refer to the official accident reports drawn up by the appropriate authorities (CMA, 2007; DGMM, 2000; DGMM, 2001; DGMM, 2006). For the purpose of analysis of causes, we will also use the accident report (DGMM, 2012) of a collision incident involving the ferry *Millenium II*, which occurred in January 2012.

From the accident reports, it is observed that the main causes for collision between RoPax ships in the area are due to the following:

- ➢ Failure to comply with the International Regulations for Preventing Collisions at Sea (COLREG). This mainly relates to rule 7: Risk of collision, and rule 8: Action to avoid collision.
- ➢ Inadequate surveillance on the bridge. This deals with both visual and radar surveillance. This cause would also be classified as failure to comply with COLREG under rule 5: look-out.
- ➢ Poor visibility due to fog. Evidence suggests that the frequent fogs in the SOG can hinder safe navigation in the area. The occurrence of collisions under such circumstances would appear to be associated with a failure to comply with COLREG rule 19: Conduct of vessels in restricted visibility.

Table 3
Incidents involving RoPax ships during period 2000–2011 in the SOG.

Nº	Ship	IMO Nº	Accident	DATE
1.	Al Mansour	7360629	Collision	05/08/2001
2.	Al Mansour	7360629	Collision	18/04/2007
3.	Atlas	7361049	Collision	28/11/2006
4.	Avemar Dos	9170183	Collision	28/11/2006
5.	Ciudad de Ceuta	7387249	Collision	16/07/2000
6.	Ciudad de Málaga	908001	Collision	18/04/2007
7.	Ciudad de Tánger	6611095	Collision	16/07/2000
8.	Le Rif	7719430	Fire/Explosion	21/04/2008
9.	Euroferrys Pacífica	9235866	Contact	14/08/2011
10.	Ropax 1	7822861	Contact	13/12/2008
11.	CF Atlas	7361049	Damage Hull/Machinery	06/03/2010
12.	Euroferrys Pacifica	9235866	Damage Hull/Machinery	02/05/2010

Table 4
Identified Hazards for maritime traffic of RoPax ships in the Strait of Gibraltar sorted by number of votes.

#	HAZARDS	Distribution of votes			
		YES	NO	Average	Votes
1	Fatigue: tiredness of officer on watch (OOW) and crew (e.g. long working hours with few breaks, increased administrative load or reduction of staff)	15	0	100%	15
15	Non-compliance with COLREG	11	4	73%	15
4	OOW distracted by doing other tasks during watch	8	7	53%	15
16	Frequency of fog	8	7	53%	15
20	Light pollution in the Bay of Algeciras hindering the identification of navigational aids.	6	9	40%	15
29	High presence of fishing boats in the Traffic Separation Scheme (TSS) and in the vicinity of the city of Tangier.	6	9	40%	15
6	Routine work on liners interrupted for attending to conflict situations (e.g. in port calls)	5	10	33%	15
30	Collision in the precautionary area at the east end of the Strait (crossing between Algeciras and Ceuta) due to the high density of traffic.	5	10	33%	15
32	Density of traffic in the TSS lanes with little room for manoeuvre	5	10	33%	15
38	Occupation of areas at the entrance to the Bay of Algeciras by ships which are *off limits*	5	10	33%	15
43	Auxiliary vessels in the Bay of Algeciras which do not comply with the COLREG	5	10	33%	15
57	Failure to report ship movements by the Port of Gibraltar	5	10	33%	15
63	Competition between ferries to be the first to reach port and claim a mooring berth	5	10	33%	15

- ➢ Unsafe speed. Related to: (a) those collisions where ships were navigating in reduced visibility and did not reduce their speed as is required by COLREG rule 6: safe speed; (b) as a consequence of the high speeds reached by High Speed Crafts (HSCs) under pressure to meet schedule times.
- ➢ Poor or non-existent 'ship to ship' and 'ship to shore' communication. There are several accidents in which the ships involved have not established communication between themselves before collision. This also applies to VTS on shore and ships, characterized by the poor, insufficient, or lack of information being transmitted.

3.3. HAZID using expert judgement

With the aim of incorporating the creative analytical element in identifying the hazards which pose a threat to safe traffic of RoPax ships in the SOG, a HAZID study has been carried out using expert judgement.

The hazards identified by the experts are shown in Table 5, sorted by number of votes obtained. The table only shows those hazards which were voted by at least a third of the experts. This provides a total of 13 hazards.

3.4. Calculation of the rates and indices of risk for the HAZID

So that the hazards can be classified according to their index of risk, the experts gave each hazard a rating depending on the frequency with which it occurs and the severity of the consequences.

In this way, the hazards identified in Table 4 were re-introduced to the experts so that they could assign a value to each hazard depending on the index of frequency and severity outlined above. The results from the sum of each scale are shown in Table 5, where the hazards appear in order from the highest to the lowest index of risk.

It also shows the risk matrix developed with reference to the Risk

Table 5
Hazards identified for RoPax ships in the Strait of Gibraltar sorted by index of risk.

	HAZARDS	FI	SI	RI
57	Failure to report ship movements by the Port of Gibraltar (Gibraltar on shore station)	5.77	2.69	**8.46**
1	Fatigue: tiredness of officer of the watch (OOW) and crew (e.g. long working hours with few breaks, increased administrative load or reduction in staff)	4.92	3.15	**8.08**
63	Competition between ferries to be the first to reach port and claim a mooring berth	4.92	2.69	**7.62**
6	Routine work on liners interrupted for attending to conflict situations (e.g. in port calls)	4.92	2.62	**7.54**
29	High presence of fishing boats in the Traffic Separation Scheme (TSS) and in the vicinity of the city of Tangier.	5.08	2.38	**7.46**
32	Density of traffic in the TSS lanes with little room for manoeuvre	4.85	2.31	**7.15**
38	Occupation of areas at the entrance to the Bay of Algeciras by ships which are *off limits*	4.62	2.31	**6.92**
4	OOW distracted by doing other tasks during watch	3.62	2.92	**6.54**
20	Light pollution in the Bay of Algeciras hindering the identification of navigational aids.	4.31	2.23	**6.54**
43	Auxiliary vessels in the Bay of Algeciras which do not comply with the COLREG	4.15	2.23	**6.38**
30	Collision in the precautionary area at the east end of the Strait (crossing between Algeciras and Ceuta) due to the high density of traffic.	3.73	2.54	**6.27**
15	Non-compliance with COLREG	3.38	2.69	**6.08**
16	Frequency of fog	3.54	2.54	**6.08**

Index (Table 6). The different levels of the matrix represent the index of risk for each hazard both quantitatively and qualitatively, from low to high risk. Therefore, green indicates those hazards which have a low risk (risk rating 2–5), yellow indicates those hazards which have a moderate risk (risk rating 6–7), and red is attributed to those hazards which have a high risk index (risk rating 8–9).

Based on the results, it can be concluded that according to expert opinion, the **failure to report ship movements by the Port of Gibraltar** and **fatigue among crew members** are the hazards which are identified as being of highest risk index. Regarding the failure to report ship movements by the Port of Gibraltar, the high index of risk is due to its rate of frequency, which scores between frequent and reasonably probable. Fatigue also borders on reasonably probable. In both cases, the consequences are considered significant.

The rest of the hazards shown in Table 6 fall under the 'considerable' risk category and ways to reduce them should also be considered.

In order to show uncertainty of main hazard outcomes in both severe (consequences) and expected frequency (probability), Tukey box plots are performed (McGill et al., 1978). Fig. 3 shows the distribution of the probability and consequence variables to both events: (57) failure to report ship movements by the Port of Gibraltar and (1) fatigue among crew members. In addition, according to the proposal of Goerlandt and Reniers (2016), the qualitative strength-of-evidence assessment has been performed using a 3-level categorization of each applicable evidence category, namely expert judgments and assumptions. A traffic light symbolism is applied to rate each evidence category, whereas green/-yellow/red means strong/medium/red. The evidence for probability and consequence is for the main risk events are performed in Fig. 3. For each event, each evidence type is assessed using a set of evidential qualities described in Table 7. See Goerlandt and Reniers (2016) for further details.

4. Risk analysis

4.1. Accidents statistics and frequency analysis

Casualty statistics analysis has been carried out on the basis of historical data for the period 2000–2011. The fleet statistics for the same period was obtained by the Spanish Maritime Safety Agency.

Table 8 shows the records of incidents and their frequencies. Two types of frequency have been calculated for this study:

a) Frequency per ship year: where the number of the fleet at risk corresponds to the total number of RoPax that operated in the area during the specified period.
b) Frequency per movement year: where the number of the fleet at risk corresponds to the total number of records of ship movements underway in the area during the specified period.

Previous studies for RoPax ships (DNV, 1996) referring to North West European experience for the period 1978–1994 and (IMO, 2008a,b) referring to world-wide fleet for the period 1994–2004, have only calculated the frequencies per ship year. However, it seems appropriate to perform a calculation of frequencies by ship movements since the risk of an accident will be greater the more the ship moves. As the SOG is an area controlled by a VTS, it is possible to get the movement ship records

Table 6
Matrix and Risk levels.

	Severity			
Frequency	Minor	Significant	Severe	Catastrophic
Frequent	8	9	10	11
	7	8	9	10
Reasonably probable	6	7	8	9
	5	6	7	8
Remote	4	5	6	7
	3	4	5	6
Extremely remote	2	3	4	5

Established by IMO, 2012.

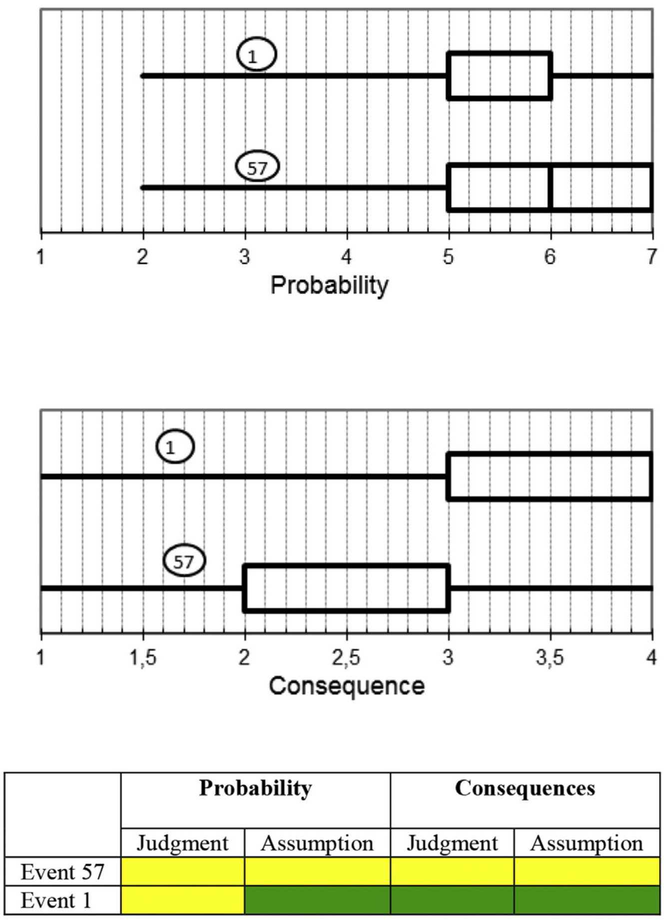

Fig. 3. Tukey box plots and strength-of-evidence assessment to main risk event.

Table 7
Evidential characteristics and criteria for strength-of-evidence rating for judgment and assumption evidence types based on Goerlandt and Reniers (2016).

Evidence type	Strong	Medium	Weak
Judgments	Broad intersubjectivity: more than 75% of peers support the judgment	Moderate intersubjectivity: between 25% and 75% of peers support the judgment	Predominantly intersubjectivity: less than 25% of peers support the judgment
Assumptions Agreement among peers	Many (more than 75%) would have made the same assumption	Several (between 25% and 75%) would have made the same assumption	Few (less than 25%) would have made the same assumption

for the established period.

Table 8 shows the frequency of collisions in RoPax ships is the highest value compared to other categories of incidents. The frequency of collisions is estimated to be 3.65E-02 per ship year. If the collision involving the *Millenium II* of 2012 is introduced, the collision frequency becomes 3.84E-02 per ship year. Table 8 also shows that the frequency of collisions expressed in movement ships year at SOG for the period 2000–2011 is estimated to be 1.83E-05 for RoPax and 8.89E-06 for rest of the fleet. This indicates that the frequency of collisions in RoPax is higher in relation to the rest of the fleet.

4.2. Calculation of consequences

4.2.1. Introduction to risk criteria

Risk acceptance criteria used in this study have been determined from the relevant literature (Skjong et al., 2007; IMO, 2008a; IMO, 2012).

Individual risk is the risk of death, injury and illness experienced by a single individual (crew member or passenger) in a given time period, who, in our case, is exposed to hazards relating to RoPax operations. The individual risk is usually expressed as the frequency of an individual fatality per year. IMO (2012) proposes a series of criteria for individual risk in shipping operations at the same level as those used by the UK Health and Safety Executive. These criteria are shown in Table 9. (see Table 10).

Social Risk is the average risk regarding the number of deaths, experienced by a whole group of people (crew member or passengers) traveling on a ship. Social Risk is usually taken as the risk of death and is typically expressed as Potential Loss of Life (PLL) or FN-diagrams (IMO, 2012). In this study, we use PLL, defined as the expected number of deaths for a year.

4.2.2. Mortal incidents

Once the risk criteria have been established, it is necessary to estimate the individual and social risks derived from this study.

There is only an accident registered in RoPax ship during the period 2000–2011, where there were mortal victims: the collision in the ferry Ciudad de Ceuta, with five fatalities. Table 9 presents the calculation for the potential loss of life during the period 2000–2011 at the SOG. The PLL is estimated to be **2.60E-02 per ship year.**

4.2.3. Risk model

In order to calculate a consequences level which is not only based on historical data, a risk model to estimate the level of consequences has been developed. A high-level model risk for collisions in RoPax vessels underway at the SOG was established through the elaboration and quantification of an ET. The selection of this initiating event (collision) is in agreement with the outcome of the HAZID work through the consideration which all identified hazards may cause one collision. In addition, as it can be seen from the frequency analysis, this initiating event represents 58% of all incidents involving RoPax ships in the SOG.

Fig. 4 presents the generic collision ET based on RoPax fleet at the SOG during the period 2000–2011. The frequency for collision incidents estimated is **3.65E-02 per ship year.** Data used and assumptions made are the follows:

Level 1: Casualty data for RoPax at the SOG indicate that during the period 2000–2011, of the 7 recorded collision casualties, 6 (86%) are collisions under way and only one collision is striking whilst at berth. These percentages are used as the branch probabilities on the event tree.

Level 2: Of the total collisions under way, 5 (83%) are recorded as minor incidents and 1 (17%) represent a serious casualty.[2]

Level 3: The probability the ship being the struck or the striking ship is assumed to be 50%–50% (Konovessis et al., 2008).

Level 4: None of the collisions occurred during the period 2000–2011 in the SOG involving RoPax ships, resulted in flooding or fire onboard the ship. Due to the limited number of collisions in the area, other references based on relevant previous studies (IMO, 2003; IMO, 2008a; Vanen and Skjong, 2004) were taken into account to estimate the branch probability of flooding or fire occurring on the struck ship. In this respect, it is considered that the probability of flooding into a struck ship after a collision is 50%.

It is assumed that the probability of fire is zero.

In the same way, it is assumed that the probability of flooding on a

[2] A collision is considered serious if as result of it has been one or multiple fatalities, or damage to the vessel that has halted service or total loss. Those collisions where only ship damages occurred and only reparations were needed are considered minor incidents.

Table 8
Number of incidents and frequencies in SOG (2000–2011).

TYPE	Incidents				Frequency (per movements ships year)		Frequency (per ship year)
	Total fleet	RoPax	Total fleet	RoPax	Total Fleet	RoPax	RoPax
Collision	14	7	27%	58%	1.20E-05	1.83E-05	3.65E-02
Grounding	9	0	17%	0%	7.69E-06	0	0
Wrecked	3	0	6%	0%	2.56E-06	0	0
Fire/explosion	5	1	10%	8%	4.27E-06	2.61E-06	5.21E-03
Contact	6	2	12%	17%	5.13E-06	5.22E-06	1.04E-02
Hull- machinery damage	15	2	29%	17%	1.28E-05	5.22E-06	1.04E-02
Total	**52**	**12**	**100%**	**100%**	**4.44E-05**	**3.13E-05**	**6.25E-02**
Movements Total Fleet in risk (2000–2011)					**1170120**		
Movements RoPax in risk (2000–2011)					**383213**		
RoPax fleet in risk (2000–2011)					**192**		

*Note: Movements Fleet in risk for the period 2000–2011 was provided by Spanish Maritime Safety Agency. The RoPax fleet in risk has been estimated on the basis of 16 RoPax ships in operation.

Table 9
Individual risk criteria (IMO, 2012).

CRITERIA	Values
Maximum tolerable risk for crew members	10^{-3} per year
Maximum tolerable risk for passengers	10^{-4} per year
Negligible risk	10^{-6} per year

Table 10
Potential loss of life for RoPax in SOG.

	Incidents	Fatalities	PLL (per ship year)	%
Collision	1	5	2.60E-02	100%
Grounding	0	0	0.00E+00	
Flooding	0	0	0.00E+00	
Impact	0	0	0.00E+00	
Fire	0	0	0.00E+00	
Total	**1**	**5**	**2.60E-02**	**100%**
RoPax Fleet in risk (2000–2011)			192	

ship striking is 5%. It is understood that damage to the striking ship is limited to her bow area, where the collision bulkhead is, hence avoiding water ingress beyond the collision bulkhead.

Level 5 and 6: Branch probabilities in these levels are adopted from relevant results from (IMO, 2003; IMO, 2008a).

It is noticed that we distinguish two cases for impacts: one involving fatalities due the impact, and the most common case of impacts not resulting in fatalities. This is due to the fact that the only collision case involving fatalities in our study can be classified as an impact involving fatalities. This is reflected in the ET. We estimate the corresponding branch probabilities in the event tree on the following assumption: just in one of 5 collisions there have been produced mortal victims, that means that 80% have produced no mortal impacts and 20% mortal impacts.

4.2.3.1. Risk calculations and reference data. Fort the calculation of individual risk the following is assumed:

➢ Average number of crew on RoPax ships operating in the area is 30.
➢ Average maximum carrying capacity is 780 passengers.
There are different fluctuations of number of passengers depending to the seasonal period. According to this and to maximum capacity of 780 passengers, is assumed:
a) 30% of trips carrying full passengers load (780 passengers)
b) 40% of trips carrying half of maximum passengers load (390 passengers)
c) 30% of trips carrying 35% of maximum passenger load (273 passengers)

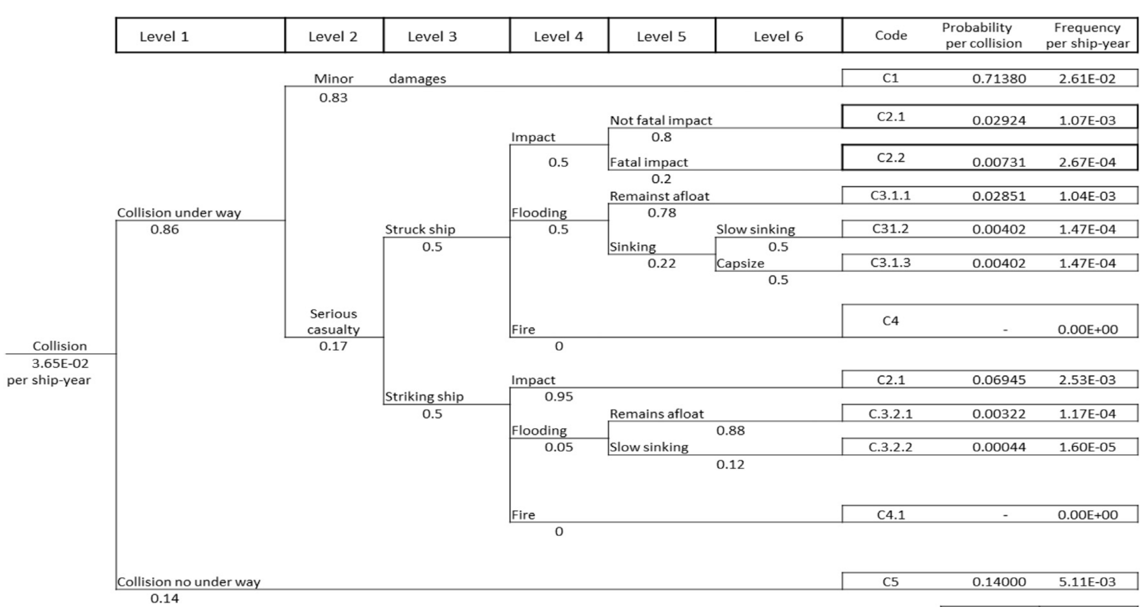

Fig. 4. Event tree for collisions involving RoPax ships.

These percentages are based on expert opinions, captain and officers, currently employed by shipping companies.

➢ Average fatality rates used for the different potential scenarios are the same used in (IMO, 2008a,b; DNV, 1996) namely a 12% fatality for flooding incidents leading to slow sinking and 66% for incidents leading to rapid capsize.

There are not probabilities of fatalities for these cases which the ship had only impact without flood. The cruise ships FSA study (IMO, 2008c) includes fatality rates for the impact scenario only. Due to differences between the types of ships of each study and the number of passengers, it does not seem appropriate to rely on their results.

According to our data, the following assumptions could be made:

a) On board of *Ciudad de Ceuta* ferry (only collision with fatalities) had 331 people of which 5 died in the collision. The averages fatality rate is 0.015.
b) If the average number of persons on board a RoPax ship at half load in the SOG is 420 people and there were seven collisions, this represents 2940 persons exposed to the collision. As for those people only there were 5 deaths, the mortality rate will be 0.17% for all ships, representing 0.02% of each ship.

As shown, the results are so low (0.015–0.02) we could disregard this risk. Furthermore, the assumptions are based on our registered accidents, representing a very limited number of cases.

Table 11 present the risk calculations for the outcomes of collision on the basis of the event tree of Fig. 4.

4.2.3.2. Individual risk calculation on basis collision risk model. Table 12 summarizes the calculations presented.

The individual risk calculated by the collision risk model is **1.17E-0 4 per year;** assuming the ship being at sea and a person being onboard for the full year. To estimate of the individual risk experienced by crew members and passengers, the following considerations can be made:

➢ For crew members: assuming that the ship operates 24 h a day, of which half (12 h) is in navigation and there is a crew rotating of 50-50 each day, the model predicts an overall individual risk for crew of **2.92E -05 per year.** But usually in these vessels (object of this study) it is that there are several crews for one ship, ensuring periods of rest/holiday.
Thus we can further assume:
a) If there is a period of rest generated 1:1, i.e. one working day corresponds to a day of rest, equivalent to 4 crews for one ship, the overall individual risk becomes **1.46E- 05 per year.**
b) If the period of rest is generated 2:1, i.e. one working day corresponds to a half of rest, equivalent to 3 crews for one ship; the overall individual risk becomes **1.95E - 05 per year.**

➢ For passenger: assuming that the average duration of a trip is 90 min, so a return trip is 3 h, we have:
a) For a passenger traveling once a year (round trip) the average individual risk is 4.01E -08 per year.
b) For a passenger who usually makes a trip (round trip) a week for a year the individual risk is 2.08E -06 per year. This probability could be applied to truck drivers who regularly use these lines.

Table 12
Collision risk model results.

	Frequency (ship year)	Individual risk (year)	PLL (ship year)	Falalities (year)
Collision	3.65E-02	1.17E-04	5.85E-02	1

Table 11
Risk Calculations for collision outcomes.

Calculation for 810 persons on board						
Code	Description	Frequency (per ship year)	Fatality Percentage	Individual Risk (per year)	Fatalities (per collision)	PLL (per ship year)
C3.1.2	Serious collision, struck ship, flooded, slow sinking	4.41E-05	12	5.29E-06	97.2	4.29E-03
C3.1.3	Serious collision, struck ship, flooded, rapid capsize	4.41E-05	66	2.91E-05	53.6	2.36E-02
C3.2.2	Serious collision, striking ship, flooded, slow sinking	4.80E-06	12	5.76E-07	97.2	4.67E-04
				3.50E-05		**2.83E-02**
Calculation for 420 persons on board						
Code	Description	Frequency (per ship year)	Fatality percentage	Individual Risk (per year)	Fatalities (per collision)	PLL (per ship year)
C3.1.2	Serious collision, struck ship, flooded, slow sinking	5.88E-05	12	7.06E-06	50.4	2.96E-03
C3.1.3	Serious collision, struck ship, flooded, rapid capsize	5.88E-05	66	3.88E-05	277,2	1.63E-02
C3.2.2	Serious collision, striking ship, flooded, slow sinking	6.40E-06	12	7.68E-07	50.4	3.23E-04
				4.66E-05		**1.96E-02**
Calculation for 303 persons on board						
Code	Description	Frequency (per ship year)	Fatality percentage	Individual Risk (per year)	Fatalities (per collision)	PLL (per ship year)
C3.1.2	Serious collision, struck ship, flooded, slow sinking	4.41E-05	12	5.29E-06	36.4	1.60E-03
C3.1.3	Serious collision, struck ship, flooded, rapid capsize	4.41E-05	66	2.91E-05	200	8.82E-03
C3.2.2	Serious collision, striking ship, flooded, slow sinking	4.80E-06	12	5.76E-07	36.4	1.75E-04
				3.50E-05		**1.06E-02**
			TOTAL	**1.17E-04**	**TOTAL**	**5.85E-02**

Considering the Fig. 5, it can be concluded that individual risk levels during a collision are within the ALARP (as low as reasonably practicable) region for both passenger and crew members. It would be desirable to reduce that risk as long as feasible.

Potential Loss of Life is 5.85E-02 ship-years, equivalent to 1 death per year.

5. Comparison with previous studies

A comparison with frequencies calculated in (DNV, 1996) referring to North West European experience for the period 1978–1994 and (IMO, 2008a,b) referring to world-wide experience for the period 1994–2004 is attempted in this section. The following are the points that can be made:

- **Collision.** The frequency of collisions world-wide during the period 1994–2004 was 1.25E-02 per ship year (IMO, 2008a,b). From Table 8, the frequency of collisions at SOG for the period 2000–2011 is estimated to be 3.65E-02 per ship year. **This indicates a frequency 2.92 times higher in the SOG.**
  If the frequency of collisions under way is compared, it can be shown that: the frequency of collisions under way at North West Europe during the period 1978–1994 was 1.32E-02 per ship year (DNV, 1996); and 7.88E-03 per ship year for word-wide during the period 1994–2004 (IMO, 2008a,b). From Table 8 and considering that collisions under way represent 86% of the total frequency, as explained in section 4.1, the frequency of collisions under way at SOG for the period 2000–2011 is estimated to be 3.12E-02 per ship year. **This indicates a frequency 2.36 times higher in the SOG with respect to NW Europe and 3.96 times higher with respect to world-wide exposure.**
- **Contact.** The frequency of contact at North West Europe during the period 1978–1994 was 4.90E-02 per ship year (DNV, 1996); and for world-wide during the period 1994–2004 was 1.25E-02 per ship year (IMO, 2008a,b). From Table 8, the frequency of contact at SOG for the period 2000–2011 is estimated to be 1.04E-02 per ship year. **This indicates a frequency 4.71 times higher in NW Europe and 1.2 times higher in world-wide exposure with respect to SOG.**
- **Fire.** The frequency of fires at North West Europe during the period 1978–1994 was 1.00E-02 per ship year (DNV, 1996); and for word-wide during the period 1994–2004 was 8.28E-03 per ship year (IMO, 2008a,b). From Table 8, the frequency of fires at SOG for the period 2000–2011 is estimated to be 5.21E-03 per ship year. **This indicates a frequency 1.92 times higher in NW Europe and 1.59 times higher in world-wide exposure with respect to SOG.**
- **Overall frequency.** The overall frequency for all critical scenarios (collisions under way, groundings, impacts, fires and flooding) at North West Europe during the period 1978–1994 was 9.44E-02 per ship year (DNV, 1996); and for word-wide during the period 1994–2004 was 4.05E-02 per ship year (IMO, 2008a,b). From Table 8, the overall frequency at Strait of Gibraltar for the period 2000–2011 is estimated to be 4.69E-02 per ship year. **This indicates a frequency 2 times higher in NW Europe and 1.16 times lower in world-wide exposure with respect to SOG.**

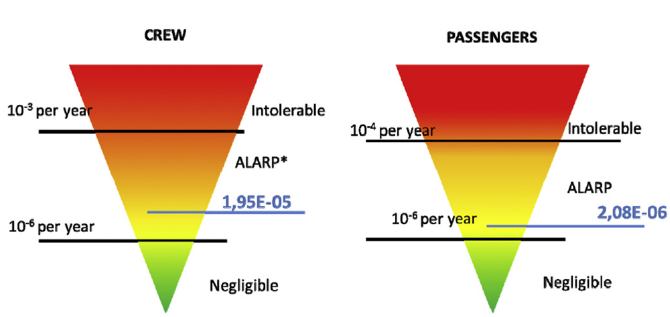

Fig. 5. Individual risk levels for RoPax ships in SOG.
ALARP* (As low as reasonably practicable). It means that risks fall within this region have to be reduced unless there is a disproportionate cost to the benefits obtained.

It is noticed that for grounding and flooding the accident frequency is estimated to be zero at the SOG for the period examined.

It is evident from the above analysis and comparison that collision frequency in the SOG area is very much higher compared with experience from North-West Europe (DNV, 199NW) and world-wide (IMO, 2008a, b). It is significant that, studying a particular geographical area, such as the SOG, the concentration of collisions involving RoPax fleet is greater in relation to another area (NW Europe experience).

However, due to differences in reporting to both database and periods, the differences between frequencies calculated above should be used as reference only. In this respect, an early study (Papanikolaou et al., 2015) gives an overview of all basic merchant ship types in terms of accidents' occurrence, frequencies and consequences for the period 1990–2012. This research uses the same resource as us – IHS Sea-web® database- and therefore it analyzes the same accidents type.

The outcomes of the research showed above indicate that the overall frequency of serious accident's occurrence in RoPax ships during the period 2000–2012 was 4.39E-02 per ship year. The overall frequency at Strait of Gibraltar for the period 2000–2011 is estimated to be 6.25E-02 per ship year. **This indicates a frequency 1.42 times higher in the SOG.** In addition, the frequency of collisions in RoPax world fleet during the period 2000–2012 was 5.69E-03 per ship year. The frequency of collisions at SOG for the same period is estimated to be 3.84E-02 per ship year. **This indicates a frequency 6.7 times higher in the SOG.**

6. Analysis and discussion of the results

Based on historical accident data analysis and expert judgement, the main hazards associated to the navigation of RoPax ships in the SOG are:

a) Communication problems 'ship to shore' and 'ship to ship'

The lack of a formal procedure for the exchange of information between the VTS in Algeciras and the Port of Gibraltar can mean that vessels coming into or going out of the bay of Algeciras do not know the exact movements of other ships that are sailing or operating in the same area. In fact, the failure of the Gibraltar Port Authority to report ship movements has been identified by the experts as the hazard with the highest risk factor given its frequency rate. A limited level of navigational assistance for ships has also been detected on the part of the on shore stations and ports (DGMM, 2012), especially in conflict situations. All this is exacerbated by the lack of communication between ships that are in situations where collision is imminent.

b) Fatigue

It appears to be an inconsistency that despite 100% of the participants in the expert judgement process voting fatigue as one of the main hazards affecting navigation in this area, it was not contemplated as a cause in any of the official reports on the collisions that have occurred in the past.[3] It is important to emphasise that according to the experts, this hazard is classified with a high risk factor. Therefore, action should be taken to reduce this situation.

c) Non-compliance with COLREG

Regarding this matter, both studies appear to agree that failure to

[3] The official report on the collision between the *Ciudad de Ceuta* and the *Ciudad de Tanger* mentions fatigue as an underlying or remote cause, which lessens its significance.

comply with some of the COLREG rules are direct causes of collisions. There was a failure to observe rules 7 and 8 in all cases. If the accident occurred, then it seems logical that it was because one of these rules was not followed.

d)Inadequate vigilance and distraction of OOW

Although inadequate surveillance comes under non-compliance with COLREG, it is worth explaining this factor in greater detail.

On passenger ships, the usual procedure is to have surveillance on the bridge by an on-duty officer and a lookout. There can even be two officers in some cases. However, the official collision reports studied show this type of vigilance to be far from effective. The lack of vigilance, both visual and through navigational aids, was identified as a cause of collision.

The routine of the journey in regular lines, detracting attention due to situations of conflict, the OOW being distracted by other tasks during the watch, stress, tiredness, and even the automation of the bridge equipment, could be underlying causes which lead to a poor or inadequate surveillance.

e) Overconfidence on the part of the OOW

It is often the case that the OOW has too much faith in the vessel's capabilities (e.g. manoeuvrability or speed). This excess confidence is what can often produce, for example, drastic manoeuvres in order to avoid collision between HSCs and ships in transit, which is an abuse not only of the regulations but also of good seamanship.

f) Fog

Poor visibility as a direct consequence of the emergence of fog is considered as a determining factor detrimental to safe navigation in this area.

g) Light pollution

The difficulty of port calls in the Bay of Algeciras at night with poor visibility is well-known. This is a result of the high level of light pollution in the area (due to the location of the ports of Algeciras and Gibraltar, the refinery at San Roque, etc.), which at times can make both the visual navigational aids and the lights from other boats imperceptible. This can lead to confusion on the part of the OOW on some occasions. This pollution, to a lesser extent, also affects the area to the south of the Strait, in the vicinity of Ceuta.

h) High presence of fishing boats in the area

The existence of Moroccan fishing vessels in the vicinity of the TSS at the point of Cape Spartel, often compromises the safety of the vessels in transit. This is aggravated by the deployment of driftnets by these vessels for fishing. These nets clog the area and compromise the safety of the vessel propulsion systems.

Fishing vessels carrying the Spanish flag do not normally cause conflict situations with the TSS, as these boats fish inside the traffic separation zone. However, the movements of these vessels to the place of fishing can pose a threat to navigation.

i) Density of traffic in the area

The geographical location of the SOG makes it a privileged enclave as the gateway to the Mediterranean from the Atlantic Ocean. Thus, it is one of the main shipping areas in the world. Approximately 110,000 vessel movements are recorder every year, resulting in a very congested area, complicating safe navigation through its waters.

j) Occupation of areas at the entrance to the Bay of Algeciras

As commented earlier, the Strait is one of the main navigational areas, so for this reason, the ports located in the area have enhanced their provisioning and bunkering services, as is the case with the ports of Algeciras and Gibraltar. Therefore, the ships which arrive in the bay for provisioning often use the outer limits of the area to carry out these operations. These boats are regarded as *off limits*.

The gathering of these boats, which sit at the entrance to the bay impede the safe transit in this area to a large extent.

k) Competition between ferries

Although there is no accident report which refers to this matter, the experts believe that this does occur in the area and is detrimental to safe navigation. Commercial pressure to meet service timetable schedules can sometimes mean that ferries from different companies compete during their voyages to see who can arrive first at port for mooring, request pilotage, etc.

In the light of the foregoing, some risk control measures could be advised as follow:

➢ Regarding to main identified hazards related with human factors, such as fatigue, overconfidence and lack lookout of OOW; the RoPax ships owners/operators are recommended to review the operational procedures of the Safety Management System to establish clear instructions that promote safety of navigation and the environment and, through appropriate supervision, ensure that the operational procedures are complied with. In particular, the following should be addressed:
   1. Maintaining a proper lookout at all times.
   2. The provision of effective bridge resource management and bridge team.
   3. Revision of the rest hours of the crew members.

➢ Regarding to hazard related with technician factor such as the communication problems 'ship to shore' and 'ship to ship'; this research suggests establishing formal links/communications between the two port authorities -Gibraltar and Algeciras-to ensure a full exchange of traffic information.

In addition, on the bases of the risk analysis results, it is observe that collision accidents are the most common accident involving RoPax ships. Also, the frequencies of occurrence's collisions in the SOG are greater than frequencies of previous studies.

Two types of incident frequencies were calculated: frequency per ship-year and frequency per movements-year.

However, the authors consider more appropriate to perform a calculation of frequencies by ship movements whenever possible since the risk of an accident will be greater the more the ship moves.

Finally, risk model for collisions estimates that the individual risk levels for both crew and passenger are inside to the ALARP region. It would be desirable to reduce that risk as long as feasible.

7. Conclusions

In this paper we presented the results of a risk analysis study for RoPax ships in the Strait of Gibraltar. Hazard identification has been carried out using a combination of two standard techniques: Historical Accident Data Analysis and Expert Judgement, both performed as the first step in the study. Also, a high-level model risk for collisions was established through of an even tree, to determinate the safety level of RoPax ships in the area.

According to the results from the HAZID, it is concluded that failure to report ship movements by the Port of Gibraltar and fatigue among crew members are the hazards which are identified as high risk indices. Therefore, it is recommended that specific studies be carried out to reduce their incidence. In this respect, potential risk control measures have been proposed such as:

a. to establish formal links/communications between the two port authorities -Gibraltar and Algeciras-to ensure a full exchange of traffic information.
b. to review the operational procedures of the Safety Management System to establish clear instructions that promote safety of navigation and the environment.

In addition, the present study illustrates current levels of safety in terms of accidental frequency for the total fleet in general and RoPax fleet in particular. The frequencies have been calculated per ship/year and per ship-movements/year. In this respect, the authors consider more appropriate to perform a calculation of frequencies by using ship movements for a specific area whenever possible.

From the results, we find that collisions are the most common accident scenarios affecting RoPax ships. Also, the frequencies of collisions occurrence in the SOG are greater than frequencies calculated in previous studies. Especially, if for the same period, the world RoPax fleet is compared with the RoPax fleet in the SOG.

Finally, risk model for collisions estimates that the individual risk levels for both crew and passenger are inside to the ALARP region. On this basis, a future research in continuation of this study would be performed to promote risk control options and to reduce the safety levels of RoPax ships in the area.

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